ATLAS OF FUNCTIONAL NEUROANATOMY

SECOND EDITION

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SECOND EDITION

WALTER J. HENDELMAN, M.D., C.M.

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DEDICATION

I wish to dedicate this book to people who have made a meaningful impact on my life
as a professional, both teacher and scientist, and as a person.

To my wife and life partner, Teena
and to our daughter, Lisanne
and sadly now to the memory of our daughter, Devra

To the many teachers and mentors and colleagues in my career as a neuroscientist,
and particularly with respect and gratitude to

Dr. Donald Hebb
Dr. Richard Bunge
Dr. Malcolm Carpenter

To all those students, staff, and colleagues who have assisted me in this endeavor
and to all the students who have inspired me in this learning partnership.

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PREFACE

This atlas grew out of the seeds of discontent of a teacher attempting to enable medical students to understand the neuroanatomical framework of the human brain, the central nervous system. As a teacher, it is my conviction that each slide or picture that is shown to students should be accompanied by an explanation; these explanations formed the basis of an atlas. Diagrams were created to help students understand the structures and pathways of the nervous system and each illustration was accompanied by explanatory text, so that the student could study both together.

The pedagogical perspective has not changed over the various editions of the atlas as it expanded in content, but the illustrations have evolved markedly. They changed from simple artwork to computer-based graphics, from no color to 2-color, to the present edition in full color. The illustrations now include digital photographs, using carefully selected and dissected specimens.

Most of the diagrams in the atlas were created by medical students, with artistic and/or technological ability, who could visualize the structural aspects of the nervous system. These students, who had completed the basic neuroanatomy course, collaborated with the author to create the diagrams intended to assist the next generation of students to learn the material more easily and with better understanding. I sincerely thank each of them for their effort and dedication and for their frequent, intense discussions about the material (please see the acknowledgements). They helped decide which aspects should be included in an atlas intended for use by students early in their career with limited time allotted for this course of study during their medical studies.

This atlas has benefited from the help of colleagues and staff in the department of which I have been a member for over 30 years, and from professional colleagues who have contributed histological and radiological enhancements, as well as advice. Their assistance is sincerely appreciated.

The previous edition of this atlas included a CD ROM containing all the images in full color. At that time, few texts had such a learning companion. It is to the credit of CRC Press that they were willing to accept the idea of this visual enhancement as an aid to student learning. The CD-ROM accompanying this new edition of the atlas, thanks to another student, employs newer software that allows the creative use of "rollover" labeling, and also adds animation to some of the illustrations (please see the User's Guide).

A final comment about the word "functional" in the title is appropriate. The central nervous system, the CNS, is a vast, continually active set of connections, ever-changing and capable of alteration throughout life. The orientation of the written text is to describe both the structural aspects of the CNS and the connections between the parts, and to explain the way those structures of the brain operate as a functional unit. In addition, there are clinically relevant comments included in the descriptive text, where there is a clear relation between the structures being described and neurological disease.

No book could be completed without the support and encouragement of the people who are part of the process of transforming a manuscript to a published work, from the publisher and the project editor, to the technical staff that handles the illustrations, to the proofreaders and copyeditors who work to improve and clarify the text. Each individual is an important contributor to the final product, and I wish to thank them all.

I sincerely hope that you, the learner, enjoy studying from the *Atlas of Funtional Neuroanatomy* and its accompanying CD-ROM, and that the text and illustrations, along with the dynamic images, help you to gain a firm understanding of this fascinating, complex organ—the brain.

Walter J. Hendelman, M.D., C.M.
Ottawa, Canada

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AUTHOR BIOGRAPHY

Dr. Walter Hendelman, M.D.,C.M., is a Canadian, born and raised in Montreal. He did his undergraduate studies at McGill University in science with honors in psychology. As part of his courses in physiological psychology, he assisted in an experimental study of rats with lesions of the hippocampus, which was then a little known area of the brain. At that time, Professor Donald Hebb was the chair of the Psychology Department and was gaining prominence for his theory known as "cell assembly," explaining how the brain functions.

Dr. Hendelman proceeded to do his medical studies at McGill. The medical building is situated in the shadow of the world-famous Montreal Neurological Institute (MNI) where Dr. Wilder Penfield and colleagues were forging a new frontier in the understanding of the brain. Subsequently, Dr. Hendelman completed an internship and a year of pediatric medicine, both in Montreal.

Having chosen the brain as his lifelong field of study and work, the next decision involved the choice of either clinical neurology or brain research—Dr. Hendelman chose the latter, with the help of Dr. Francis McNaughton, a senior neurologist at the MNI. Postgraduate studies continued for 4 years in the United States, in the emerging field of developmental neuroscience, using the "new" techniques of nerve tissue culture and electron microscopy. Dr. Richard Bunge was his research mentor at Columbia University Medical Center in New York City, while his neuroanatomy mentor was Dr. Malcolm Carpenter, author of the well-known textbook Human Neuroanatomy.

Dr. Hendelman returned to Canada and has made Ottawa his home for his academic career at the Faculty of Medicine of the University of Ottawa, in the Department of Anatomy, now merged with Physiology and Pharmacology into the Department of Cellular and Molecular Medicine. He began his teaching in gross anatomy and neuroanatomy, and in recent years has focused on the latter. His research continued, with support from Canadian granting agencies, using nerve tissue culture to examine the development of the cerebellum; more recently he has been involved in studies on the development of the cerebral cortex. Several investigations were carried out in collaboration with summer and graduate students and with other scientists. He has been a member of various neuroscience and anatomy professional organizations, has attended and presented at their meetings, and has numerous publications on his research findings.

In addition to research and teaching and the usual academic "duties," Dr. Hendelman was involved with the faculty and university community, including a committee on research ethics. He has also been very active in curriculum planning and teaching matters in the faculty. During the 1990s, when digital technology became available, Dr. Hendelman recognized its potential to assist student learning, particularly in the anatomical subjects and helped bring the new technology into the learning environment of the faculty. Recently, he organized a teaching symposium for the Canadian Association of Anatomy, Neurobiology and Cell Biology on the use of technology for learning the anatomical sciences.

In 2002, Dr. Hendelman completed a program in medical education and received a Master's degree in Education from the Ontario Institute of Studies in Education (OISE), affiliated with the University of Toronto. In the same year, following retirement, he began a new stage of his career, with the responsibility for the development of a professionalism program for medical students at the University of Ottawa.

As a student of the brain, Dr. Hendelman has been deeply engaged as a teacher of the subject throughout his career. Dedicated to assisting those who wish to learn functional neuroanatomy, he has produced teaching videotapes and four previous editions of this atlas. As part of this commitment he has collaborated in the creation of two computer-based learning modules, one on the spinal cord based upon the disease syringomyelia and the other on voluntary motor pathways; both contain original graphics to assist in the learning of the challenging and fascinating subject matter, the human brain.

In his nonprofessional life, Walter Hendelman is a husband, a father, an active member of the community, a choir member, a commuter cyclist, and an avid skier.

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ACKNOWLEDGMENTS

This atlas has been a cumulative "work-in-progress," adding and altering and deleting material over time. The illustrations have been created by talented and dedicated individuals—artists, photographers, and students, and with the help of staff and colleagues—whom the author has had the pleasure of working with over these many years.

PREVIOUS EDITIONS

The atlas was originally published with the title of *Student's Atlas of Neuroanatomy*. The diagrams in the first editions were created by Mr. Jean-Pierre Morrissey, a medical student at the time he did the work. To these were added photographs of brain specimens taken by Mr. Stanley Klosevych, who was then the director of the Health Sciences Communication Services, University of Ottawa. Mr. Emil Purgina, a medical artist with the same unit, assisted in these early editions and added his own illustration. Dr. Andrei Rosen subsequently created the airbrush diagrams (note particularly the basal ganglia, thalamus, and limbic system) and expanded the pool of illustrations. For the previous edition of the atlas under its new title The Atlas of Functional Neuroanatomy many of the earlier illustrations were replaced by computer-generated diagrams done by Mr. Gordon Wright, a medical illustrator. Mr. Wright also put together the CD-ROM for the previous edition, which contained all the illustrations in this atlas. The efforts of the staff of the University of Ottawa Press and of W.B. Saunders, who published the previous editions, are very much appreciated and acknowledged.

PRESENT EDITION

ILLUSTRATIONS AND PHOTOGRAPHS

Dr. Tim Willett, a medical student during the preparation of the atlas, created many new illustrations and retouched several others. In addition, all the photographs were redone, using original dissections and digital photography, with the assistance of Dr. Willett.

CD-ROM

Mr. Patrick O'Byrne, a doctoral candidate in the nursing program at the Faculty of Health Sciences, University of Ottawa, has put together the present CD-ROM, using Macromedia Flash software to create "rollover" labeling and animated illustrations.

MEDICAL ARTIST

Mr. Mohammad Dayfallah created the overview diagrams and those of the ventricular system.

RADIOGRAPHS

Colleagues at the Ottawa Hospital contributed the radiographs to the previous edition, and all have been replaced with new images, using the upgraded capability of the newer machines and accompanying software.

HISTOLOGICAL SECTIONS

Colleagues and staff of the Department of Pathology, Children's Hospital of Eastern Ontario, are responsible for preparing the histological sections of the human brainstem, added to in the present edition by sections of the human spinal cord.

SUPPORT

The previous editions were supported, in part, by grants from Teaching Resources Services of the University of Ottawa. The present edition received support from CRC Press.

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The support of my home department at the Faculty of Medicine of the University of Ottawa, initially the Department of Anatomy and now called the Department of Cellular and Molecular Medicine, including colleagues, secretaries, and other support staff in the gross anatomy laboratory, is gratefully acknowledged.

Finally, thanks to the many classes of students, who have provided inspiration, as well as comments, suggestions and feedback.

With thanks to all

Dr. Walter J. Hendelman

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Sensory:

Dorsal columns & medial lemniscus
(fine touch, vibration & proprioception from the body)

Anterolateral system
(pain, temperature & crude touch from the body)

Trigeminal system
(touch, pain, temperature & proprioception from the head)

Special senses
(vision, audition & taste)

Reticular Formation
(arousal & regulation of muscle t one and reflexes)

Motor:

Voluntary
(movement of body and face)

Parasympathetic
("rest & digest")

Other
(non-voluntary motor & visual coordination)

Vestibular nuclei & tracts
(balance & gravity adjustments)

Cerebellum & associated tracts
(motor coordination)

Special Nuclei:

Substantia nigra
(motor initiation)

Red nucleus & tract
(non-voluntary motor)

Other
(miscellaneous)

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USER'S GUIDE

COLOR CODING

Color adds a significant beneficial dimension to the learning of neuroanatomy. The colors have a functional role in this atlas, in that they are used consistently for the presentation of sensory, motor, and other components. The following is the color coding used in this atlas, as shown on the opposite page:

Sensory (nuclei and tracts)	
Dorsal Column – Medial Lemniscus	Cobalt Blue
Anterolateral System (Pain and Temperature)	Deep Blue
Trigeminal Pathways	Purple
Special Senses (Audition, Vision, Taste)	Violet
Reticular Formation	Yellow
Motor (nuclei and tracts)	
Voluntary	Cadmium Orange
Parasympathetic	Orange
Other Motor (e.g. visual motor)	Light Red
Vestibular (nuclei and tracts)	Lime Green
Cerebellum (nuclei and tracts)	Turquoise
Special Nuclei:	
Substantia Nigra	Brown
Red Nucleus (and tract)	Red
Other (e.g., area postrema)	Peach

For students who enjoy a different learning approach, a black and white photocopy of the illustration can be made and then the color added, promoting active learning.

Some students may wish to add color to some of the airbrush diagrams, including the basal ganglia, thalamus, and limbic system.

REFERENCE TO OTHER FIGURES

Reference is made throughout the atlas to other illustrations that contain material relevant to the subject matter or structure being discussed. Although this may be somewhat disruptive to the learner reading a page of text, the author recommends looking at the illustration and the accompanying text being referenced, in order to clarify or enhance the learning of the subject matter or structure.

Clinical Aspect

Various clinical entities are mentioned where there is a clear connection between the structures being discussed and a clinical disease, for example, Parkinson's disease and the substantia nigra. In Section C, the vascular territories are discussed and the deficits associated with occlusion of these vessels is reviewed. Textbooks of neurology should be consulted for a detailed review of clinical diseases (see the Annotated Bibliography). Management of the disease and specific drug therapies are not part of the subject matter of this atlas.

Additional Detail

On occasion, a structure is described that has some importance but may be beyond what is necessary, at this stage, for an understanding of the system or pathway under discussion. In other cases, a structure is labeled in an illustration but is discussed at another point in the atlas.

DEVELOPMENTAL ASPECT

For certain parts of the nervous system, knowledge of the development contributes to an understanding of the structure seen in the adult. This is particularly so for the spinal cord, as well as for the ventricular system. Knowledge of development is also relevant for the cerebral hemispheres, and for the limbic system (i.e., the hippocampal formation).

NOTE TO THE LEARNER

This notation is added at certain points in the text when, in the author's experience, it might be beneficial for a student learning the matter to review a certain topic; in other cases there is a recommendation to return to the section at a later stage. Sometimes, consulting other texts is suggested. Of course, this is advice only, and each student will approach the learning task in his or her own way.

THE CD-ROM

The CD-ROM adds another dimension to the learning process. Ideally, the student is advised to read the text, using *both* the text illustration and the illustration on the CD. In addition, animation has been added to certain illustrations, such as the pathways, where understanding and seeing the tract that is being described, along with the

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relays and crossing (decussation), can hopefully assist the student in developing a 3-dimensional understanding of the nervous system.

Labeling of structures on the CD-ROM has been accomplished using "rollover" technology, so that the name of the structure is seen when the cursor is on the area, or when the cursor is over the label, the named structure is highlighted in the illustration.

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FOREWORD

We are about to embark on an amazing and challenging journey — an exploration of the human brain. The complexity of the brain has not yet been adequately described in words. The analogies to switchboards or computers, although in some ways appropriate to describe some aspect of brain function, do not do the least bit of justice to the totality. The brain functioning as a whole is infinitely more than its parts. Our brains encompass and create a vast universe.

In the past decade we have come to appreciate that our brains are in a dynamic state of change in all stages of life. We knew that brain function was developing throughout childhood and this has been extended into the teen years, and even into early adulthood. We now are beginning to understand that the brain has the potential to change throughout life, in reaction to the way we live and our personal experiences in this world. The generic term for this is *plasticity*, and the changes may significantly alter the connections of the brain and its pattern of "processing" information, whether from the external world, from our internal environment, or from the brain itself as it generates thoughts and feelings.

ORGANIZATION

The *Atlas* is divided into four sections, each with an introductory text. The focus is on the illustrations, photographs, diagrams, radiographs, and histological material, accompanied by explanatory text on the opposite page.

Section A: The Atlas starts with an **Overview** of the various parts of the central nervous system, the CNS. Then we embark on an **Orientation** to the structural components of the CNS, and this is presented from the spinal cord upward to "the brain"; additional material on the spinal cord is added in other parts of the Atlas. Radiographic images have been included, because that is how the CNS will be viewed and investigated in the clinical setting.

Section B: The second section, **Functional Systems**, uses these structural components to study the sensory ascending pathways (Part I), and the various motor descending tracts (Part III), from origin to termination. Interspersed between them is a discussion of the Reticular Formation (Part II), which has both sensory and motor aspects. Included as part of the motor systems are the major contributors to motor function, the basal ganglia and the cerebellum.

Section C: The third section, **Neurological Neuroanatomy**, includes a neurological orientation and detailed neuroanatomical information, to allow the student to work through *the* neurological question**:** *Where* is the disease process occurring (i.e., neurological localization)? Because vascular lesions are still most common and relate closely to the functional neuroanatomy, the blood supply to the brain is presented in some detail, using photographs with overlays. The emphasis in this section is on the brainstem, including a select series of histological cross-sections of the human brainstem. In addition, there is a summary of the spinal cord nuclei and tracts, along with a histological view of levels of the human cord.

Section D: The section on the **Limbic System** has once again been revised. New photographs of limbic structures enhance the presentation. This material is sometimes taught within the context of other systems in the curriculum.

Annotated Bibliography

Students may wish to consult more complete texts on the anatomy and physiology of the nervous system, and certainly some neurology books concerning diseases of the nervous system. A guide to this reference material is included, with commentary, as an annotated bibliography, with an emphasis on recent publications. Added are suggestions for material available on CD-ROM, as well as the Internet. Students are encouraged to search out additional (reliable) resources of this nature.

Glossary

Much of the difficulty of the subject matter is the terminology — complex, difficult to spell, sometimes inconsistent, with a Latin remnant, and sometimes with names of individuals who have described or discovered structures or disease entities, used often by neurologists, neurosurgeons, and neuroradiologists. A Glossary of terms is appended to help the student through this task.

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